HUMANIZING MATHEMATICS THROUGH BOUNDARY CROSSING COLLABORATION

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What mathematics is and how to teach it are questions that mathematics educators constantly confront. A challenge identified in mathematics education is supporting students to see mathematics as normal human activity. Mathematics educators' viewpoints of mathematics determine whether they can recognize and exploit learning opportunities for student. This study presents the boundary crossing collaboration between two female educators within informal learning settings. Drawing on a boundary crossing learning perspective, I explored two female educators' mathematics experiences and interrogated their boundary crossing experiences as sites for humanizing mathematics. Based on this exploration, I address the possibilities for humanizing mathematics by facilitating boundary crossing between mathematics education and informal education.

Keywords: boundary crossing, informal mathematics, humanized mathematics

Introduction

In a *Journal of Research in Mathematics Education* commentary, Stephan et al. (2015) reported a challenge and an opportunity for mathematics education to support the public to understand the role of mathematics in society. To achieve the goal, the mathematics education community needs to receive widespread support to energize the public toward "changing the image of or public perception about mathematics" (p. 139). Previous studies have recognized that facilitating crossing boundary collaboration between mathematics education and other practices outside mathematics education can stimulate this initiative (e.g., Bakker et al., 2021; Stephan et al., 2015).

The current study is a boundary crossing between two female educators engaging in a collaborative relationship. Laura (pseudonym), the primary participant in the study, started the first *Girls Excelling in Math and Science* (*GEMS*) club for in 1994 and has continued her contribution to informal education to the present. I, a researcher from the mathematics education community, work alongside Laura and collaborate with her to further develop the *GEMS* program. At first, I doubted that collaboration was related to mathematics or mathematics education. Laura who has taught mathematics activities in informal spaces for more than two decades, always claims, "I am not good at math" and calls me "math person." As we continued engaging in boundary crossing collaboration, our view of mathematics and mathematics teaching began evolving. This study tends to provide a reference providing opportunities to humanize mathematics through building boundary crossing collaboration between the mathematics education community and communities outside of mathematics education.

Literature Review and Theoretical Framework

Two sets of relevant literature inform the theoretical perspective of this study. First, the literature on humanizing mathematics helps me reconceptualize mathematics and mathematics education. Following that, I describe a boundary crossing perspective which provides an analytic lens to understand Laura's and my boundary crossing experiences. In particular, four learning mechanisms were unitized to understand different stages of boundary crossing collaboration.

Humanizing Mathematics

In public, mathematics is perceived to be "difficult, cold, abstract, and in many cultures, largely masculine" (Ernest, 1996, p.802). Sam and Ernest (2000) surveyed British 548 adults, including people not indirectly involved in mathematics education and interviewed a sub-sample of 62 adults. They found one's school learning experience was one of the major influential factors for forming their image of mathematics. The public image of mathematics is also widely dispersed in popular culture. For instance, Darragh (2018) examined young adult fiction and found school mathematics was portrayed as tense, terrible, difficult, and less useful. In addition, mathematicians in many movies were depicted as exceptional people who were geniuses and born in that way that marked them as out of the ordinary (Mendick, 2005). Given the growth of future careers in science, technology, engineering, and mathematics (STEM) and the significant role of mathematics in STEM, reframing mathematics as normal, ordinary, and relevant to people is an urgent task for the mathematics education community (e.g., Darragh, 2018; Sealey & Noyes, 2010).

Researchers attempted to use the concept of *humanizing mathematics* to highlight the human practice characteristic of mathematics, shifting the public image of doing mathematics as special people to do extraordinary work. Though substantial literature uses the term *humanizing mathematics*, still, there are no agreed-upon descriptions of what mathematics is humanized and how to humanize mathematics. As early as the 1970s, researchers started to seek ways to humanize mathematics. Wheeler (1975) described humanizing mathematics is to foster students' awareness of self and the world through inner sights on mathematics, which he explicates as "the act of attention that preserves the significant parts of experience, that pegs and holds them in the self so that they are available for future use" (p. 8). Students use mathematics to understand at least part of their world, to see this part of their world through the eyes of mathematical relationships (Falkenberg, 2006).

D'Ambrosio (1985) introduced *ethnomathematics*, which refers to mathematical practices in identifiable cultural groups. Ethnomathematics recognizes that the development of mathematics is embedded in a cultural context. That is, people within various cultural groups develop unique methods and techniques to understand their realities in response to the problems they encounter (Rosa & Orey, 2008). D'Ambrosio (2015) suggested that teachers need to help students realize their full mathematical potential by acknowledging the importance of culture and bringing culturally relevant mathematics into teaching.

Rochelle Gutiérrez (2018) brought up the term *rehumanizing mathematics* to advocate for developing practices for those historically marginalized communities (i.e., Black, Indigenous and Latinx). She claimed, "a student should be able to feel whole as a person—to draw upon all of their cultural and linguistic resources—while participating in school mathematics" (p. 1). Similarly, D'Ambrosio (2001) cautioned that without a culturally relevant curriculum, most students leave school thinking that mathematics is something to be done only at school and has no relevance to their lives.

Nevertheless, school mathematics often focuses on the mastery of skills, accumulation of facts, rules, and algorithms necessary for standardized tests (Cooper, 2011). Conversely, mathematics in other contexts (i.e., designed informal learning environment) is not typically accompanied by traditional academic assessment allowing students to explore relevant mathematics and experience satisfaction in learning (Zhou et al., 2021; Nemirovsky et al., 2017). Different from the literature that tends to bring cultural knowledge into school mathematics (i.e., Gutiérrez, 2018), I conceptualize *humanizing mathematics* as a process that blurs the boundary

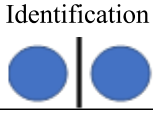
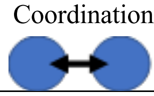
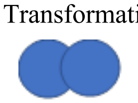
between mathematics in school and other practice, which allow teachers and students to see mathematics learning as ordinary human activity rather than special work.

Boundary Crossing Learning

Boundary crossing has become an explicit concept in communities of practice (Wenger, 1998) and the theory of expansive learning (Engestrom, 1987; 2015). Though these two theories are rooted in different learning theories, situated learning theory and sociocultural learning theory, respectively, their descriptions of boundary crossing are compatible and coincide with my literature review. Wenger et al. (2002) argued that the "learning potential of an organization lies in this balancing act between well-developed communities and active boundary management" (Wenger p. 154). Engestrom (2001) pointed out that learning is also a horizontal movement in which a learner should be approached as a whole person who participates in school and many other practices. In this study, the horizontal aspect of learning provides a powerful lens for analyzing collaboration between Laura and me from different activity systems, which is conceptualized as boundary crossing (Engestrom, 1987/2015).

Akkerman and Bakker (2011) identified four learning mechanisms at the boundaries, identification, coordination, reflection, and transformation. Akkerman and Bruining (2016) further developed the four learning mechanisms. They suggested that boundary crossing in each form can occur at institutional, interpersonal, and intrapersonal levels. For this study, I only focus on boundary crossing at the interpersonal and intrapersonal levels (i.e., interpersonal experiences between researcher and participant and intrapersonal experiences of individual researcher or participant) (see Table 1).

Table 1: Boundary Crossing Framework

Learning Mechanism	At the Interpersonal Level (Action and Interaction Between Actors from Different Practices)	At the Intrapersonal Level (Participation of a Person in Two or More Practices)
Identification 	People come to (re)define their different and complementary roles and tasks.	A person comes to define [*their*] own simultaneous but distinctive participatory positions.
Coordination 	People seek shared means or procedures for exchange and cooperative work.	A person seeks means or procedures to distribute or align [*their*] own participatory positions in multiple practices.
Reflection 	People come to value and take up another's perspective.	A person comes to look differently at their own participatory position because of the other participatory position.
Transformation 	People face a shared problem, start collaborative work, and may build group identity.	A person develops a hybridized position that integrates previously distinctive ways of thinking, doing, communicating, and feeling.

Adapted from Akkerman and Bruining (2016)

At an interpersonal level, boundary crossing is about actions and interactions between specific groups of people from different practices. I come from a mathematics education community in this study, and Laura comes from the informal education community. We establish collaborative relationships to work together on a certain project. Both Laura and I entailed multiple roles to participate in more than one separate practice at an intrapersonal level.

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Narrative Inquiry Methodology

With the goal of building a reciprocal and collaborative relationship with Laura, narrative inquiry enables me to co-construct the inquiry with the participant. Clandinin and Connelly (2000) described narrative inquiry as "a way of understanding experience. It is a collaboration between researcher and participants, over time, in a place or series of places, and social interaction with milieus" (p. 20). Clandinin and Connelly's suggestion, I engage in narrative inquiry research by embracing narratives as both the method and phenomena of study and entailing the dual role as researcher and participant in the study.

Data Source

Because of the nature of the narrative inquiry, this study's data are co-constructed between Laura and me. The narrative data consist of two forms, field texts and interviews. In this study, field texts include various forms: informal conversations, autobiographical writing, reflections, emails, etc. (Clandinin & Connelly, 2000). The field texts record ongoing interactions between Laura and me and my reflections, thoughts, and feelings in particular moments. Two interviews have been conducted to understand Laura's experiences. The first interview focused on her past experiences with mathematics and *GEMS*. The second interview focused on her reflections on the collaborative experiences with people from mathematics education, including me.

Data Analysis

The narrative data are dynamic and influenced by contextual factors and the interaction of Laura and me. Moreover, data interpretation is personal and dynamic, which requires change and rechange, often including further reading. The first data analysis stage is to transfer field texts to research texts (Clandinin & Connelly, 2000). During the transfer, I stepped back for a while from fields and shifted back to a researcher position and through the theoretical lens to view data.

I adopted Polkinghorne's (1995) analytical approaches: *analysis of narrative and narrative analysis*. The *analysis of narrative* method employs paradigmatic reasoning to collect stories as data and analyze them in descriptions of themes that hold across the stories or in taxonomies of types of stories or characters. Using *analysis of narrative* approach, I first applied boundary crossing theory. I identified learning mechanisms from the collaborative experience of Laura and me in both interpersonal level and intrapersonal level. Then, themes were identified directly from data cross Laura's and my experiences, such as becoming a teacher and being a female educator were common themes identified.

I also employed the *narrative analysis* method, which uses narrative reasoning to collect descriptions of events and synthesize or configure them into a plot in a story or stories. This method allows me to recognize plots of the narratives by reading data repeatedly. I have identified two major plots of the study: women's experiences and experiences with mathematics, which are also interwoven, sometimes entangled. The plots also determine how the stories are told: what emotions are displayed or the certain phrases or words the narrator uses, which manifests deeper layers of the narrator's identity.

Findings

Due to the page limitation, I share part of the finding from the study. First, I present Laura's experiences with mathematics in *GEMS*. Then, through a boundary crossing lens, I describe an emerging collaborative experience between Laura and me with a mathematical task. The collaboration starts from recognizing mathematics and ends to reframing mathematics, within which Laura and I coordinate with each other on the task design and reflect on our own experience.

Mathematics Was Dropped Out in GEMS

Laura recognizes that mathematics in *GEMS* presents a dilemma; on the one hand, the goal of *GEMS* is to increase girls' interest in mathematics; on the other hand, Laura has discovered that engaging girls in mathematics can create tension with another goal, presenting *GEMS* as different from school. Unlike other subjects, such as engineering or science, that are easily integrated into hands-on activities and experiments, Laura sees mathematics as built on mental strategies and memorization, which could cause girls to lose interest very quickly.

Laura has struggled with the certainty of mathematics that may diminish the passion for exploration. She has expressed concern that, as *GEMS* girls seek a correct answer, they might overlook the opportunity to discover other possibilities in the process. If a problem is challenging, it can be perceived as difficult and frustrating. Students who are not confident in mathematics thus fear failure and may lose interest and the confidence to explore. Laura said:

> I think with math—what was always so hard for me is that it's very tricky to make it not be the right answer—you see, to experiment. I don't even know how to begin. With the technology, when we would do computer stuff with kids, it's something that they could do at home. It's not just school stuff. It's something fun, and so that's what I mean—not like school. It's not intended to put math down. (Laura, Interview, August 2019)

On the *GEMS* website, we provide sample activities for leaders to use. Some activities are labeled as science or engineering on the website, and mathematics components can be identified in the activities. However, mathematics is not emphasized in the activities. I expressed my concern that mathematics is often hidden in GEMS activities. Laura proposes that leaders do not label activities at the beginning but later guide students to reflect on the subject knowledge. She said:

> There's a lot of math in there. I think we're going to have to help the leaders, not label it or maybe make it a mystery. At the end after you do these really fun activities—let's think about what kinds of categories we were using today. Were we using science or [math]? The teachers are really going to have to rethink how they bring math into *GEMS*. (Laura, Interview, August 2019)

After noticing Laura's hesitancy to communicate directly with GEMS girls about mathematics, I asked if she was concerned that by emphasizing mathematics, girls would lose interest in GEMS. Laura answered:

> No, because again, as long as we always have to keep at the front that it's not school and it's fun, I don't think there's going to be a problem. Because there's going to be hands-on activities. I'm not worried about that. I think as long as we keep those things at the top. (Laura, Interview, August 2019)

Presenting mathematics in a different way from school—fun and hands-on—is Laura's goal for promoting mathematics in *GEMS*. Laura expects we can continue to offer mathematics activities and even highlight the math and said, "I'm really interested in what you guys come up with for fun math in *GEMS*, because this could make a huge difference."

Evolving Mathematics in Collaboration

In this section, I share evolving mathematics in our collaboration. I describe a mathematics task called Quilt Problem, to illustrate informal educators as curriculum developers who capture emerging learning opportunities from everyday practice and teaching practice. Specifically, I

describe the development of the task through a boundary crossing lens (i.e., identification, coordination, reflection, and transformation).

Identification. The task started from an email from Laura to me, which was titled *I need help with a math problem.* In the email (See Figure 1.a), she said,

> Here is the quilt pattern. I am trying to figure out how to make it a little bigger because I have gorgeous fabric, and I want to expand the portions marked 28 inches wide to about 38-40 inches wide. Unfortunately, they will stay the same length. The problem I am having is many-faceted: 1) Do I make the square bigger? If so, what size? 2) Do I change the location of the angled cut to make it more proportional? 3) What will the finished size be? (Laura, Email, April 2021)

It took me quite a while to make sense of the context. Then I grabbed a piece of paper to manipulate the model, see Figure 1.b, and responded to Laura,

> If you have 40*40 fabric, you can decide the size of the quilt. It also depends on how big the square in the center you want. See the pic below. You can move the triangles to make the square inside bigger; then, the quilt will be bigger too. (Lili, Email, April 2021)

Laura replied that she did not get it. Then we set up a virtual meeting to discuss the fabric and model. Later, using geometry software, I made a model for this problem and demonstrate the relations between fabric and the final quilt (See Figure 1. c). Laura thought the visual model is very helpful for her to understand the spatial relations.

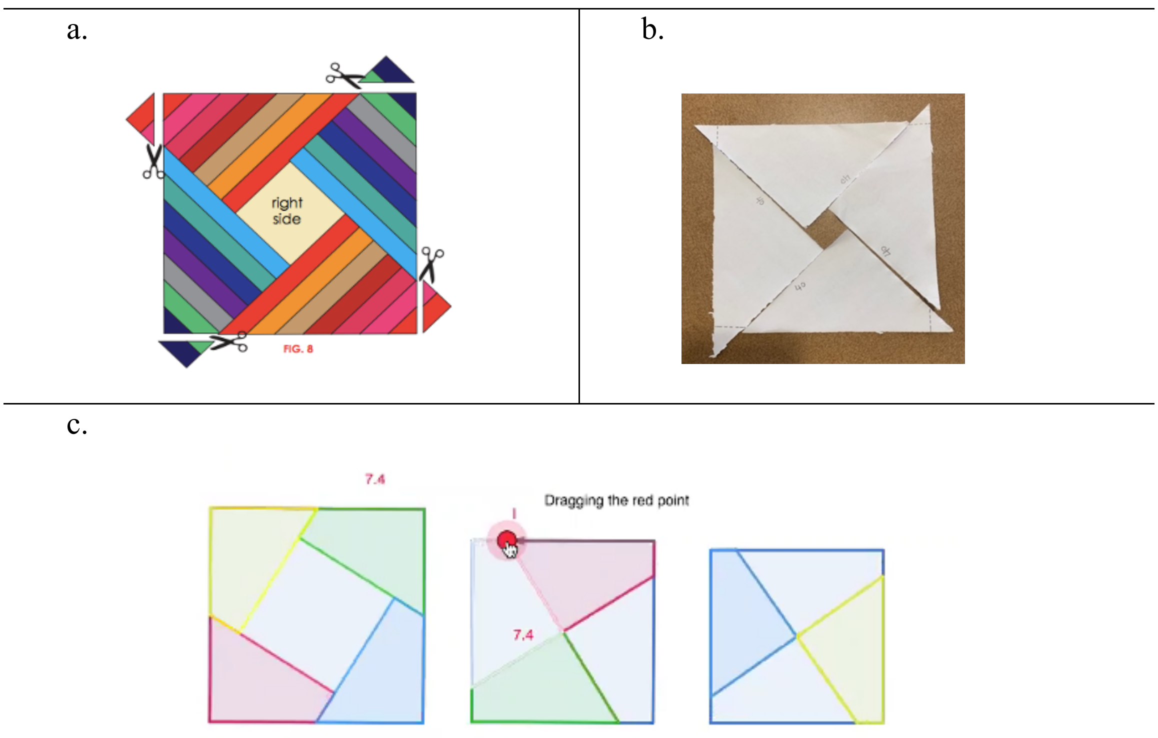

Figure 1: Quilt Problem

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Coordination. Laura and I recognized mathematics from this real-life problem and felt interesting to make this problem a mathematics task. We have worked together to develop a problem called *Ms. Jones's Quilt Problem.*

> Ms. Jones has a question. She is making a quilt for her sister. The pattern she used for the quilt is below. She has two fabulous squares of fabrics 40''x40.'' She wants the finished quilt to be a square with sides between 46''-56.'' Could you help her figure out where the cuts are and how you do you make the quilt?

I brought this task to my pre-service teachers and mathematics education colleagues to let them try and collect feedback from them.

Reflection. Laura and I both reflected on this task. Laura said**,**

> I'm clueless about spatial stuff. That is an example of my bad spatial skills. I also see my daughters' and other girls' struggles in spatial. They need to understand [spatial]; if they cannot figure out how to do it, the boys take it over. So, the only thing I want to do for GEMS is developing a spatial curriculum.

My reflection as:

> This problem is from real life and developed as a contextualized mathematics problem. However, as mathematical relationships are recognized, the context is not important anymore and is even removed in the solution process. It changes back to a pure math problem. We need to think about making mathematics tangible and engaging throughout the problem-solving process.

Laura and I were not very satisfied with the problem in the reflection. Laura thought it was *too school,* and I believed it reflects the idea of optimization, which is a goal of mathematics but not all I wanted to communicate.

Transformation. Building on our reflection, Laura and I decided to expand this task to a project. We integrate art, cultural, real-life elements, and geometry, technology, and algebra into the project. See Table 2.

Table 2: Quilt Project

Session	1	2	3	4	5	6
Topic	Knowing patterns	Appreciate quilt designs and share stories about quilts	Use Geogebra to draw your quilt design	List materials you need	Make your quilt	Exhibition
Element	Art, real life, and mathemat ics	Cultural, community, and personal assets	Mathematics, technology, and art	Mathematic s, real-life	Hands-on	Involving parents

The integration characteristic of the project involves creating a task that does not connect to one specific subject but instead transfers from a mathematics task to an integrated STEM task. Though less focused on mathematics, this provides multiple entry points for students, allowing them to bring their cultural and life experiences to the project. Laura and I both like the project and see this project as not "too school" but fun, which aligns with the mission of *GEMS*.

Discussion and Conclusion

The boundary crossing efforts in this study build a bridge between mathematics practice in school and mathematics practice in informal learning environments. Informal learning environments like *GEMS* encourage excitement, where having fun is a primary consideration for selecting and implementing activities. Such an emphasis can be potentially disruptive to the seriousness assumed to be essential in learning mathematics. Educators from the mathematics education community support identifying and making mathematics explicit in STEM integration, whereas educators from the informal education community contribute their expertise to bring excitement and engagement to mathematics learning. Learning across boundaries leads to discontinuities (Akkerman & Bruining, 2016), which can be understood as learning mechanisms to generate new practices that create a space for reframing mathematics. The new collaborative practices emerged as crossing boundary between mathematics education and informal education create a space that blurs the border of mathematics in different contexts which leads to a new understanding of mathematics as normal human practices rather than mandatory.

Humanizing mathematics requires a broader approach incorporating culturally relevant methods, objectives, and content in solidarity to reframe mathematics (Yeh & Otis, 2019). In this study, narrative inquiry provides a method that value subjective resource as a form of knowledge that sets a stage for humanizing mathematics. Moreover, the goal of the collaboration between Laura and me is to foster alternative mathematics practice. The shared objective of the collaboration is to work towards a broad understanding of mathematics that makes sense for people from inside the mathematics education community and outside of the community. Humanized mathematics consists of an accessible curriculum and culturally relevant pedagogy, which satisfies learners in working with mathematics. To humanize mathematics and make mathematics "normal and ordinary" (Darragh, 2018), mathematics education researchers need to build connections between mathematics and other practices. Efforts crossing boundaries (Akkerman & Bruining, 2016) between the mathematics education community and the informal education community bridges in-school mathematics and out-of-school mathematics, providing opportunities to humanize mathematics.

This study provides an example of building boundary crossing collaborations between the mathematics education community and other disciplines or communities outside of mathematics education to reconceptualize the understanding of mathematics. As such, the study contributes to changing the traditional image of mathematics by reframing and humanizing mathematics as a normal practice that encourages a wide range of participation in mathematics (Darragh, 2018). In particular, the effort of humanizing mathematics in this study has the potential to inspire historically underserved students in mathematics to actively participate in mathematics/STEM (e.g., Joseph et al., 2019).

Through this boundary crossing collaboration, Laura and I both have been involved in developing non-traditional mathematics curriculum and have developed a new understanding of mathematics. The unique experiences allow me to reframe and humanize mathematics by viewing mathematics experience as a human practice that positions learners and teachers as subjects interacting with mathematics. Using narrative inquiry methodology entailed the role of

researcher and participant in collaborative research, narrowing the gap between school mathematics and informal mathematics (Clandinin & Connelly, 2000). Reflecting on my own experience with mathematics learning and teaching, the image of mathematics I held likely aligns with the public image of mathematics. This study demonstrates the possibilities to change the public image of mathematics by promoting cross-disciplinary collaboration.

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